THE EFFECT OF ADAPTATION TO HYPOXIA UNDER PRESSURE-CHAMBER CONDITIONS ON TOLERANCE TO TRANSVERSE G-LOADS

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ABSTRACT: The effect of intermittent conditioning to hypoxia was studied in a pressure chamber on the tolerance of man to transverse G-loads. The conditioning was carried out by successive ascents every 3-7 days to altitudes of 4000 to 7000 m with rest periods at each altitude for 30 minutes. The duration of the training schedule was 20-25 days. It was established that after pressure-chamber conditioning an increase is noted in tolerance to G-loads, which on the average is +1.35. The increase in tolerance to G-loads after conditioning in a pressure chamber was less than after high-altitude training. The authors propose that adaptation to hypoxia may be used for purposes of pre-flight training and for increasing tolerance of the astronaut during prolonged flight before returning to Earth.

The research of many Russian and foreign investigators has established that prolonged adaptation to high-altitude conditions is one of the effective means of increasing tolerance of an organism to the effect of various adverse environmental factors (acute hypoxia, variations in temperature, radiation, etc.). Adaptation to oxygen deficiency under pressure-chamber conditions has been proposed some time ago by Russian investigators for increasing tolerance of an organism to the effect of acute hypoxia. Many investigators, in studying the mechanisms of adaptation of the human organism to high altitude, have shown that the acclimatization effect is reached only after many ascents or after many hours of remaining at high altitude [1, 5, 7-12]. /40

In the research conducted by Klein, Brüner and Jovy [13, 14] it was shown that, when man remained under high-altitude conditions, the reactions of his physiological systems are considerably improved in regard to the effect of positive G-loads due to the involvement of nonspecific mechanisms. The increase in tolerance to transversely directed G-loads was also established in experiments on animals who were adapted to conditions of hypoxia [3, 4].

We previously found an analogous effect on persons exposed to high-altitude conditions and who have shown a distinct increase in tolerance toward the effect of transversely directed G-loads [2, 3].

The results of these investigations permitted us to assume that acclimatization in mountains is one of the effective methods of nonspecific conditioning and the duration of retention of this positive effect of adaptation showed the feasibility of using this method for pre-flight training of astronauts. It is known that the oxygen factor has a definite significance in the reactions of an organism at high altitude and there are quite similar characteristics in the adaptation of an organism to pressure-chamber and high-altitude hypoxia. At the same time the method of adaptation to hypoxia under pressure-chamber conditions differs essentially as compared to acclimatization in mountains. First of all, the use of such a method is independent of seasonal variations in climate and geographical location. Secondly, adaptation to hypoxia in this case may be carried out not only in the conditioning period but also during space flight. Thirdly, it is possible to make a strict quantitative evaluation of the various effective conditions for choosing the optimal /41
one. Based on these arguments we felt that it was feasible to determine the possibility of increasing man's tolerance to the effect of G-loads after having been previously adapted to hypoxia under pressure-chamber conditions.

The investigations were carried out on four subjects who had not been previously subjected to high-altitude adaptation. Prior to conditioning in the pressure chamber, tolerance to the effect of extreme maximally endurable G-loads was determined on each of them. Endurance to G-loads was studied in a centrifuge in all cases from at least two background experiments and once (after 1-4 days) following completion of conditioning in the pressure chamber. The method used to find the limit of tolerance and registration of the physiological parameters has been discussed in previous papers (see the present collection, original pp. 7 and 17).

Pressure-chamber conditioning was conducted intermittently by successive ascents to altitudes of 4000, 5000, 5500, 6000, 6500 and 7000 m every 3-7 days. The duration of residence at each altitude was 30 minutes. The rate of ascent in the pressure chamber was equal to 25 m/sec. The duration of the entire training cycle in the pressure chamber was 20-25 days. Prior to and after conditioning, tolerance to oxygen starvation (altitude-ceiling) was determined.

For the purpose of improving respiration, the subjects were first instructed in a voluntary increase in breathing intensity while retaining the usual frequency recommended at "altitudes" above 4000 m.

In compiling data from the training schedule in the pressure chamber, the results of the investigations carried out by Vasil'yev

and Uglovaya [3] on animals, as well as the high effectiveness of intermittent conditioning in a pressure chamber, were taken into account. Here the authors showed that the increase in tolerance of animals to G-loads after intermittent and continuous conditioning in the pressure chamber was practically the same.

The results of the investigations showed that in all four subjects, after pressure-chamber conditioning, an increase was noted in their tolerance to transverse G-loads that was, on the average, +1.35 $\pm$ 0.8 (Table 1).

Individual improvements in tolerance were associated in all cases with an increase in the threshold of the onset of optical disorders and varied in a range from +0.7 to +2.5 (see the figure).

According to data from the subject's response, in three cases out of four the subjects noted an improved tolerance to G-loads after pressure-chamber conditioning. This was expressed in the easier breathing and the sensation of pressure on the chest, and by the delayed onset of optical disorders. Visual acuity, determined at different average values of the G-load with acceleration of the centrifuge, in all cases after pressure-chamber conditioning was found to be higher than with the background tests (Table 2). Thus, a corrolation was found between the improvements in the threshold of onset of optical disorders and visual acuity produced by the effect of G-load after preliminary conditioning in a pressure chamber. /42

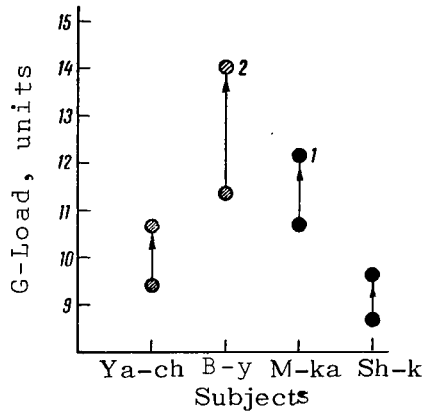
TABLE 1. CHANGE IN G-LOAD TOLERANCE AFTER PRESSURE-CHAMBER CONDITIONING

Subject	Before Conditioning	After Conditioning	Difference	Tolerance criteria
Ya-ch	9.5	10.5	+1.0	"Gray Veil"
B-y	11.5	14.0	+2.5	" "
M-ka	10.8	12.0	+1.2	"Black Veil"
Sh-k	8.8	9.5	+0.7	" "
Average	10.1 $\pm$ 1.2	11.5 $\pm$ 1.9	+1.35 $\pm$ 0.8	" "
Reliability of differences	—	—	>0.95	" "

It was interesting to compare the improvements in G-load tolerance and to acute oxygen starvation after multiple times in the pressure chamber (Table 3).

It was established that following pressure-chamber conditioning the altitude ceiling in two of the subjects increased to 1000 m, in the two others it did not change. The time of residence at high altitude was increased in three of the persons. Comparison of the individual tolerance to acute oxygen starvation and G-load revealed

similar characteristics. It was shown that in one of the subjects (Sh-k) in whom no change was noted in altitude resistance the G-load tolerance changed also very little; in two of the others an increase in altitude ceiling and threshold of G-load tolerance was observed. Here the greatest increase in G-load tolerance (+2.5) was found to be in that subject (B-y) in whom the greatest increase in altitude tolerance was also noted. /43



Change in the Level of G-Load Tolerance and Characteristics of Optical Disorders in Four Subjects After Pressure-Chamber Conditioning. 1. "Black Veil"; 2. "Gray Veil". The Arrow Shows the Direction of Improvement Following the Pressure Chamber.

Thus the results of change in altitude tolerance after repeated exposure in a pressure chamber, to a known degree, permits us to predict the change in G-load tolerance.

Of considerable significance for showing the possible mechanisms of nonspecific adaptation is the investigation of the characteristics of physiological reactions to a G-load in persons who have been adapted to hypoxia.

Of greatest interest in this respect are the results of investigations of the cardiovascular system, the systems of breathing and gaseous metabolism. For this purpose we have analyzed

TABLE 2. CHANGE IN VISUAL ACUITY UNDER THE INFLUENCE OF G-LOADS PRIOR TO AND AFTER ADAPTATION IN A PRESSURE CHAMBER.

Subject	Improvement in Threshold of Onset of Arterial Disturbances, Units	Before Adaptation Pressure Chamber		After Adaptation in Pressure Chamber	
		G-Load, Units	Visual Accuity	G-Load, Units	Visual Accuity
Sh-k . . .	+0,7	6,0—8,0	0,4	6,5—8,5	0,6
M-ka . . .	+1,2	7,5—9,1	0,3	7,5—9,5	0,4
B-y . . .	+2,5	9,0—11,0	0,5	9,0—11,0	1,0
Ya-ch . .	+1,0	7,0—9,0	0,5	8—10,0	0,5

Comment: The values of the G-load for which visual acuity was determined in the subjects are indicated.

TABLE 3. CHANGE IN ALTITUDE TOLERANCE PRIOR TO AND AFTER REPEATED EXPOSURE IN A PRESSURE CHAMBER.

Subject	Altitude Ceiling		Improvement in G-Load Tolerance, units
	Before Conditioning	After Conditioning	
Ya-ch	7 km—2 min	7 km—3 min	+1.0
B-y	7 » —1 »	8 » —3 »	+2.5
M-ka.	7 » —2 »	8 » —2 »	+1.2
Sh-k	8 » —1	8 » —1 »	+0.7

and compared the physiological improvement recorded during the action of G-loads which are identical in value prior to and after pressure-chamber conditioning. The functional state of the cardiovascular system was evaluated for all subjects based on readings of the pulse rate and the breathing rate, of an EKG in three Nebo leads, systolic pressure in the vessels of the humerus and the cochlea, based on recovery time of the physiological functions. /44

TABLE 4. CHANGE IN PULSE RATE AND BREATHING RATE DURING THE ACTION OF G-LOADS OF 8-9 UNITS PRIOR TO AND AFTER PRESSURE-CHAMBER CONDITIONING.

Subject	Improvement in G-Load Tolerance, Units	Before Conditioning		After Conditioning		Difference	
		Pulse rate beat/min	Respiration rate	Pulse rate beat/min	Respiration rate	Pulse rate beat/min	Respiration rate
Sh-k .	+0.7	102	27	102	27	0	0
M-ka .	+1.2	103	21	114	23	+6	+2
B-y . .	+2.5	107	24	109	23	+2	+2
Ya-ch	+1.0	126	24	126	30	0	+6

In all cases changes were noted in the cardiovascular readings which are characteristic of G-load effect and have already been described in a previous article. No substantial difference could be detected in the improvements in these characteristics prior to and after pressure-chamber conditioning (Table 4).

After conditioning under pressure-chamber conditions, the improvements in the electrocardiograph readings in one of the subjects was the same as with background tests; in the other three, they had individual characteristics. Thus, in the subject M-ka at the time of the background tests when the centrifuge was accelerated at a G-load of 10.8, signs of relative bradycardia were noted with

the reduction of R-R from 0.59 to 0.70 sec. After conditioning in a pressure chamber, analogous disruptions in rhythm were observed during the action of G-loads with a value of 12. In the other subjects with background rotation tests a slight non-conformity was noted in the length of the interval Q-T and R-R; the relative duration of the electrical systole was 120-130% [15]. After training /45
in a pressure chamber the EKG of these subjects acted on by large G-forces was without characteristics and the relative length of the electric systole corresponded to the frequency of the rhythm. We may assume that these improvements indicate an increase in the functional capacity of the heart muscle after adaptation to hypoxia.

TABLE 5. RECOVERY TIME OF BLOOD PRESSURE (SYSTOLIC AND DYASTOLIC) IN THE PERIOD OF AFTER-EFFECT OF THE G-LOAD PRIOR TO AND AFTER CONDITIONING IN A PRESSURE CHAMBER.

Subject	Increase in G-Load Tolerance, Units	Time, min.			Subject	Increase in G-Load Tolerance, units	Time, min.		
		Before Conditioning	After Conditioning	Difference			Before Conditioning	After Conditioning	Difference
Ya-ch	+1.0	6	2	-4	Ya-ch	+1.2	5	1	-4
B-y	+2.5	6	4	-4	B-y	+0.7	6	2	-4

TABLE 6. CHANGE IN THE AMPLITUDE OF OSCILLATIONS OF VESSELS OF THE COCHLEA ACTED ON BY G-LOADS PRIOR TO AND AFTER CONDITIONING IN A PRESSURE CHAMBER (DIFFERENCE IN % OF THE ORIGINAL VALUE).

Subject	Before Pressure Chamber Conditioning		After Pressure Chamber Conditioning	
	G-Load, units	Difference, %	G-Load, units	Difference, %
Ya-ch. .	9	— 50	9	—20
M-ka . .	11	- - 50	11	—50
B-y . . .	8	- - 10	8	—10
Sh-k . .	6	-100	7	—50

Comment: These G-loads correspond to the period of centrifuge acceleration.

The recovery time of blood pressure in the vessels of the humerus and the period of after-effect of the G-load following previous adaptation in a pressure chamber was found in all cases to be shorter than in the background tests in spite of the high value of the G-load attained (Table 5).

The amplitude of oscillations of the cochlea vessels acted on by G-loads had a tendency to be lower. After conditioning in a

pressure chamber these improvements in two instances were considerably less than with background test, in two others no difference was noted (Table 6). /46

Pulmonary ventilation and the requirements for oxygen in all background tests gradually increased in proportion to the increase in G-loads. Under the action of a G-load that is extreme in value, as a rule there was noted a decrease in the respiratory volume and pulmonary ventilation with a sufficiently high frequency of breathing. When the centrifuge was slowed down, the increase in pulmonary ventilation and the O_2 requirement was the greatest. After conditioning under pressure-chamber conditions the double-peak type of curves which characterized pulmonary ventilation and O_2 requirements did not change. However, qualitative improvements were noted. When the centrifuge was accelerated from 1 to 6 after adaptation to altitude, the increase in pulmonary ventilation and oxygen requirements were found to be more significant than in the background tests (Table 7).

TABLE 7. CHANGE IN PULMONARY VENTILATION AND OXYGEN REQUIREMENTS DURING THE ACTION OF TRANSVERSE G-LOADS PRIOR TO AND AFTER PRESSURE-CHAMBER CONDITIONING.

Subject	Difference in G-Load Tolerance, units	Pulmonary Ventilation, l/min			O_2 Requirement, ml/min			Oxygen Debt		
		Before Conditioning	After Conditioning	Difference	Before Conditioning	After Conditioning	Difference	Before Conditioning	After Conditioning	Difference
Ya-ch	+1,0	15,8 *	17,3	+1,5	380	420	+40			
		23,0 **	23,4	+0,4	512	550	+38	730	269	—461
M-ka	+1,2	9,6 *	11,5	+1,9	351	392	+41			
		14,1 *	14,2	+0,1	305	368	+63	0	0	0
Sh-k	+0,7	9,6 *	10,8	+1,2	302	310	+ 8			
		13,0 **	17,4	+4,4	390	430	+40	37	61	+24

* When the centrifuge is accelerated from 1 to 6.
** When the centrifuge is slowed down from 6 to 1.

It follows from Table 7 that the increase in pulmonary ventilation and O_2 requirements when the centrifuge slows down after adaptation to high altitudes is obviously due to the decrease in the oxygen debt during the effect of G-loads in spite of the fact that the size of the effect was 1-1.2 greater in comparison with the background investigation. In one case (Sh-k), where after conditioning in the pressure chamber an increase was observed in the oxygen debt, the increase in G-load tolerance was found to be the least.

The obtained data indicate an increase in the effectiveness of /47
the operational system of external respiration after pressure-chamber conditioning when the centrifuge is accelerated.

The change in the characteristics of external respiration and gaseous metabolism after pressure-chamber conditioning was similar to the improvements in the systems after acclimatization in mountains.

Based on data from the investigation at the time of the motor response reaction to light and the EEG in all four subjects, no difference was found in the characteristics of the physiological reaction to G-load before and after pressure-chamber conditioning.

Thus the data which we obtained would permit us to assume that repeated ascents in a pressure chamber may be one method for increasing the man's tolerance to the effect of transversely directed G-loads. However, unlike the previous series of experiments carried out under high-altitude conditions, in this case only one of the basic factors, i.e., the lowered partial pressure of oxygen, facilitated discovery of compensatory mechanisms which aid in improved G-load tolerance. The passive residence of subjects at high altitudes under pressure-chamber conditions prevented any effect from the other important factor, i.e., motor activity which, in conjunction with hypoxia, would probably guarantee a greater increase in the functional reserve. The obtained data show that improvements in tolerance after high-altitude acclimatization were on the average found to be somewhat higher than after pressure-chamber conditioning.

This difference is also explained apparently by the considerable muscular activity under high-altitude conditions.

In the investigations by Vasil'yev et al. [3] on animals, the high effectiveness was distinctly shown in this respect of active acclimatization in comparison with passive acclimatization. There is no doubt that the characteristics of a mountainous climate, such as temperature of the air, solar radiation, ionization, etc., have distinct significance for developing the processes of nonspecific adaptation. However, they play a secondary role. Based on these discussions we may assume that multiple ascents in a pressure chamber in conjunction with physical training under high-altitude conditions may be still a more effective method of increasing the tolerance of man to the effect of transverse G-loads.

The obtained positive effect of nonspecific influence of hypoxia has great practical significance and may be used both for pre-flight training and for increasing the astronaut's tolerance prior to return to Earth after prolonged flight.

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